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## Dual Linearly Polarized Microstrip Array Antenna

M. S. R Mohd Shah, M. Z. A Abdul Aziz and M. K. Suaidi  
*Faculty of Electronic and Computer Engineering,  
 Universiti Teknikal Malaysia Melaka,  
 Hang Tuah Jaya, Ayer keroh, 75450, Melaka.  
 Malaysia*

M. K. A Rahim,  
*Radio Communication  
 engineering,  
 Faculty of Electrical Engineering,  
 Universiti Teknologi Malaysia,  
 81300 Skudai, Malaysia.*

### 1. Introduction

The wireless communications systems have been greatly expand to the high performance applications. Nowadays, most of the wireless communications systems offers high data rate transmission and keep growing for higher data rates technology. Then, the communication devices were design to be small in size, low power consumption, low profile and practical.

### 2. Important

Recently, Multiple Input Multiple Output (MIMO) has become popular research topic among researchers for development of a new wireless communications technology. The system capacity can be increase with deployment of MIMO technique in the communications system. Thus, the used of high frequency bandwidth can be avoid since this method required high cost implementation. High transmitted power also is not required because all transmitted branch will transmit same power in MIMO system. There are three major studies in MIMO which are research on array antenna and adaptive signal processing, research on information theory and coding algorithm and research on MIMO channel propagation (Nirmal et al., 2004).

MIMO channel capacity can be increase with the increase of number of transmitter and receiver. When the number of the antennas used is fixed, the channel capacity is related to the spatial correlation and the diversity gain from antenna spacing configuration at

transmitter or receiver. The spatial correlation in MIMO system is always exploited by using diversity technique such as frequency diversity, space diversity, time diversity and polarization diversity. Polarization diversity can be achieved by deploying two or more different polarized antenna at transmitter or receiver. The transmitted signal with different polarized in MIMO channel will improved the un-correlation channel between transmitter and receiver (Collins, Brain. S, 2000)(Manoj. N et al.,2006)(Byoungsun. L, 2006).

A few technique have been introduce to obtain dual polarized antenna such as aperture-coupled microstrip antenna, two port corporate feed network and two or more probe feeds technique. The aperture coupled microstrip antenna was developed by using cross slot aperture at the plane between feed line plane and ground plane. Each aperture excite the patch in single direction and two orthogonal modes can be excited from the cross aperture (Ghorbanifar &Waterhouse., 2004)(S. B. Chakraby et al., 2000). Besides, the used of T, H and U slot configuration can offer better isolation between the two ports (Sami Hienonen et al., 1999)(S. Gao et al., 2003)(S. Gao & A. Sambell, 2005)(B. Lee, S. Kwon& J. Choi, 2001). A good isolation between ports will lead to good axial ratio if the circular polarized is used. Thus, the combination of the slots and slots modifications has been widely investigated by the researchers as report in (S. K. Padhi et al., 2003)(A. A. Serra et al., 2007)( Kin-Lu Wong et al., 2002) (B. Lindmark, 1997). Higher gain for these technique can be achieve by using number of patch and array feed network (M. Arezoomand et al., 2005)(J. Choi & T. Kim, 2000). This technique requires relatively complicated feed arrangement or multilayer construction in order to reduce the coupling between two feed lines (W.-C. Liu et al., 2004).

Two port feed network technique will excite two independent dominant mode from the patch with fed at the dual central point. Thus, the patches mode will degenerates at the far fields and produce the orthogonal and linear polarized at angles of designed (LJ du Toit & JH Cloete, 1987). A patches with corner fed also can excite two orthogonal polarized with equal amplitude and in phase. The corner fed method produce higher isolation as compared to edge centre fed method (Shun-Shi Zhong et al., 2002) (ShiChang Gao & Shunsui Zhong, 1998)(S. C. Gao et al., 2001).

Dual linear polarized antenna can also develop by using square patch with two feed probes. Each feed probe will generate one polarized signal primarily such as horizontally and vertically polarization (K. Woelders & Johan Granholm, 1997). The cross polarization at far field will cause the field generate by the patches is not purely orthogonal. These problem can be reduce by integrate bend slots in the square patch and reducing the antenna size as well (W.-C. Liu et al., 2004)(Keyoor Gosalia & Gianluca Lazzi, 2003).

Most of the dual polarized microstrip antenna was design to generate signals with vertical and horizontal polarized or +45 and -45 polarized. Vertical and horizontal polarized can be excite from patch with vertical and horizontal in position. However, +45 and -45 polarized signal excite from the patch which are slant at the angle of +45 and -45 from the principle plane. This topic will discussed the design of  $\pm 45$  dual polarized microstrip antenna with a single port at the single layer substrate. The further investigate also will be done to investigate the dual polarized signal excitation for array technique.

All the design will used 1.6 mm FR4 substrate with  $\epsilon_r = 4.7$  and  $\tan\delta = 0.019$ . First, the design simulation and measurement of single patch slant at  $\pm 45$  will be presented. Then, further investigation for array implementation also will be discussed later. The Computer Simulation Technology (CST) Studio 2006 was used as CAD tools and fabrication was done by using chemical etching technique.

### 3. Design specification

As this design was intended to confirm the basic concept, it was decided to build the antenna using a best and successful approach. The specification such as the dielectric substrate and impedance matching will be meeting and find. Appropriate components will choose including the SMA/coaxial connector and FR4 board. A single element of square geometry  $+45^\circ$  and  $-45^\circ$  slanted polarized as shown in Figure 3.2 and Figure 3.3 can be designed for the lowest resonant frequency using transmission line model.

The substrate used is FR4 with a dielectric constant of 4.7 and a thickness of 1.6 mm. The loss tangent of the substrate is 0.019. After all dimensions have been calculated, the design would then be simulated in CST Studio Suite 2006 software to obtain the return loss, radiation pattern, and VWSR.

#### 3.1 Transmission line model

The method used that allows the design of square microstrip patch antenna is the transmission line model. A square microstrip antenna fed to excite only one dominant mode ( $TM_{10}$  or  $TM_{01}$ ) has a single resonance which may be modeled as this method. These values are designated  $R_a$ ,  $L_a$ ,  $C_a$  as shown in Fig 1. This figure represents the inset fed patch antenna which the arrangement of feed is shown in Figure 2. At resonance the relationship between the resonant frequency  $f_0$  and the patch model values  $L_a$  and  $C_a$  are;

$$f_0^2 = \frac{1}{L_a C_a} \quad \text{Equation 3.1}$$

When the patch is resonant the inductive and capacitive reactance of  $L_a$  and  $C_a$  cancel each other, and the maximum value of resistance occurs. If the patch is probe fed and thick, the impedance at resonance will have a series inductive reactance term  $L_s$ ;

$$Z_{in} = R_a + j f_0 L_s \quad \text{Equation 3.2}$$

In order to obtain the values of  $L_a$  and  $C_a$  from measured or computed data one must subtract the series inductive reactance from the impedance. The value of two points either side of resonant frequency is obtained.

$$f_1 = f_0 - \Delta f_1 \quad \text{Equation 3.3}$$

$$f_2 = f_0 + \Delta f_2 \quad \text{Equation 3.4}$$

With the subtraction of the series inductance, the reactance now changes sign either side of  $f_0$ . The admittance at each frequency may be expressed as;

$$Y_1 = \frac{1}{R_a} + j f_1 C_a + \frac{1}{j f_1 L_a} = G_1 + j B_1 \quad \text{Equation 3.5}$$

$$Y_2 = \frac{1}{R_a} + j f_2 C_a + \frac{1}{j f_2 L_a} = G_2 + j B_2 \quad \text{Equation 3.6}$$

The conductance  $G_1$  and  $G_2$  in the equivalent circuit of the patch antenna will account for the losses through radiated power, and the susceptance  $B_1$  and  $B_2$  will give a measure of the reactive power store in neighborhood of the radiating slots. Since the slots are identical  $G_1 = G_2 = G$ , the expression of  $B_1$  and  $B_2$  is;

$$B_1 = f_1 C_a - \frac{1}{f_1 L_a}$$

Equation 3.7

$$B_2 = f_2 C_a - \frac{1}{f_2 L_a}$$

Equation 3.8

Solving the equations for C the expression can be obtained as;

$$C_a = \frac{f_1 B_1 - f_2 B_2}{f_1^2 - f_2^2}$$

Equation 3.9

The susceptance, B can be obtained by equation below;

$$B = k_0 \Delta l \frac{\sqrt{\epsilon_{eff}}}{Z_0}$$

Equation 3.10

Where;  $\Delta l$  = Extended incremental length  
 $\epsilon_{eff}$  =Effective dielectric constant

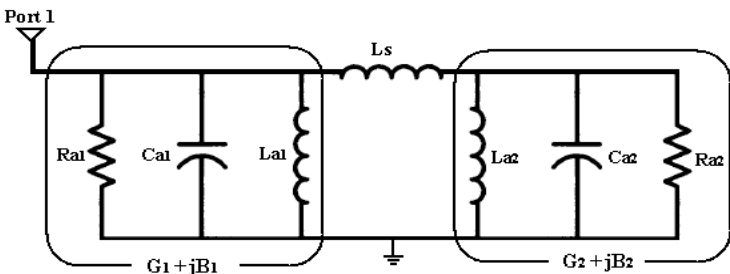


Fig. 3.1. Equivalent circuit for proposed microstrip patch antenna

3.2 Microstrip patch design

3.2.1 Square Patch

The design of the square shape patch follows the equation for designing the rectangular shape patch. The same length and width of the patch of the antenna was made to ease the design steps. Inset feeding is introduced into the design to offset the feeding location to the point where matched impedance can be achieved. The design calculation for the square patch has been discussed in this section. The parameters that needed to be calculated are the length of the patch, the inset feed and the feed line’s length as shown in Fig 3.2.

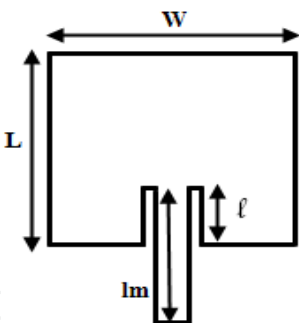


Fig. 3.2. Layout of the square patch.

The calculated parameters of the patch have been calculated as shown in Table 3.1. The input impedance level of the patch can be control by adjusting the length of the inset. Variations in the inset length do not produce any change in resonant frequency, but a variation in the inset width will result in a change in resonant frequency (M. Ramesh & K. B. Yip, 2003). The feed line is made to be a quarter wavelength of the operating frequency. The width of patch can be determined using the equation 3.11.

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} \tag{Equation 3.11}$$

The  $\epsilon_0$  and the  $\mu_0$  are the permittivity and the permeability in free space respectively. The equation  $\frac{1}{\sqrt{\mu_0\epsilon_0}}$  can also be interpreted as the speed of light,  $c$  which is  $3\times10^8$  m/s. The symbol  $f$  is the resonant frequency that the antenna intended to be operating and  $\epsilon_r$  is the permittivity of the dielectric. The patch’s length can be calculated using the equations 3.12. The length’s extension,  $\Delta L$  and the effective permittivity,  $\epsilon_{\text{reff}}$  have to be calculated before calculating the length of the microstrip patch as shown in equation 3.13 and 3.14. The  $h$  is the height of the substrate while the  $W$  is the width of the patch as calculated before.

$$L = \frac{1}{2f_r\sqrt{\epsilon_{\text{reff}}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \tag{Equation 3.12}$$

$$\Delta L = 0.412h \frac{(\epsilon_{\text{reff}}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{\text{reff}}-0.258)(\frac{W}{h}+0.8)} \tag{Equation 3.13}$$

$$\epsilon_{\text{reff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \tag{Equation 3.14}$$

where:

- |   |                                      |
|---|--------------------------------------|
| $f$ = Operating frequency   | $\mu_0$ = Permeability in free space |
| $\epsilon_r$ = Permittivity of the dielectric                       | $W$ = Patch’s width                  |
| $\epsilon_0$ = Permittivity in free space                           | $h$ = Thickness of the dielectric    |
| $\epsilon_{\text{reff}}$ = Effective permittivity of the dielectric |                                      |

The type of feeding technique that will be used is the inset feed technique. It is one of the best feeding techniques and it is also easy to control the input impedance of the antenna. The input impedance level of the patch can be control by adjusting the length of the inset. The calculation of the inset fed is shown in the equations 3.19 which show the resonant input resistance for the microstrip patch.

$$\lambda_0 = \frac{c}{f}$$

Equation 3.15

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{reff}}}$$

Equation 3.16

$$G_1 = \frac{W}{120\lambda_0} \left[ 1 - \frac{1}{24} (k_0 h)^2 \right]$$

Equation 3.17

where:

$$k_0 = \frac{2\pi}{\lambda_g}$$

Equation 3.18

So, for resonant input resistance,  $R_{in}$

$$R_{in}(L = \ell) = \frac{1}{2G_1} \left( \cos^2 \frac{\pi}{L} y_0 \right)$$

Equation 3.19

$L$  is the length of the patch,  $\ell$  is the length of the inset, and  $G_1$  is the conductance of the microstrip radiator. As reported in frequency (M. Ramesh & K. B. Yip, 2003), the calculations for finding the inset length can be simplified as shown in the equation 3.20. This equation is valid for  $\epsilon_r$  from 2 to 10. Using the equation below helps to ease the calculation for the inset length of the microstrip antenna.

$$\ell = 10^{-4} \left( \frac{0.001699\epsilon_r^7 + 0.13761\epsilon_r^6 - 6.1783\epsilon_r^5 + 93.187\epsilon_r^4 - 682.69\epsilon_r^3 + 2561.9\epsilon_r^2 - 4043\epsilon_r + 6697}{\phantom{0.001699\epsilon_r^7 + 0.13761\epsilon_r^6 - 6.1783\epsilon_r^5 + 93.187\epsilon_r^4 - 682.69\epsilon_r^3 + 2561.9\epsilon_r^2 - 4043\epsilon_r + 6697}} \right) \frac{L}{2}$$

Equation 3.20

where:  $\epsilon_r$  = Permittivity of the dielectric  
 $L$  = Length of the microstrip patch

The summary of the calculated characteristics of the designed patch antenna is shown on Table 3.1. All calculation for square patch dimension is applied onto CST Studio Suite 2006.

Patch characteristics	Dimension (mm)
Microstrip line width ( $w_0$ )	3.00
Patch width ( $W$ )	37.00
Effective dielectric constant ( $\epsilon_{eff}$ )	4.35
Extended incremental length ( $\Delta L$ )=	0.732
Patch effective length ( $L_{eff}$ )=	29.94
Patch actual length ( $L$ )	28.48

Table 3.1. summary of patch characteristics



Figures 3.3 show simulation result of return loss for single element obtained by using CST Studio Suite software. According to this figure, the result of the return loss of a single patch design has a good result at frequency of 2.4GHz which is -31.88dB which could be considered as a good result. Where at the resonant frequency of 2.4GHz which is the intended design frequency has a value of -10dB. The bandwidth obtained from the simulation of this microstrip antenna is 108.7 MHz which in percentage value is 4.05%.

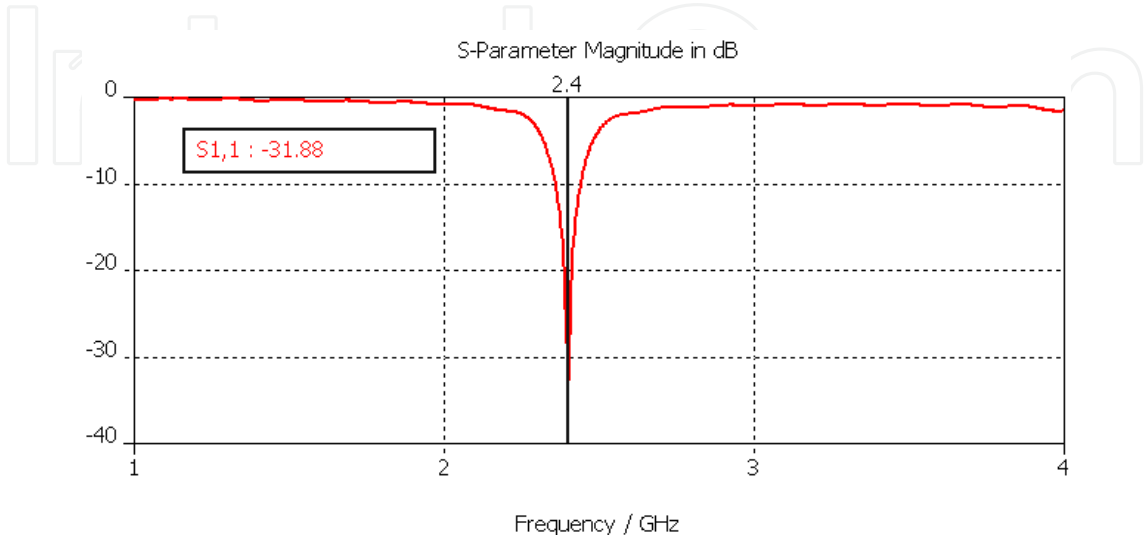


Fig. 3.3. Return loss simulation results of a single patch design.

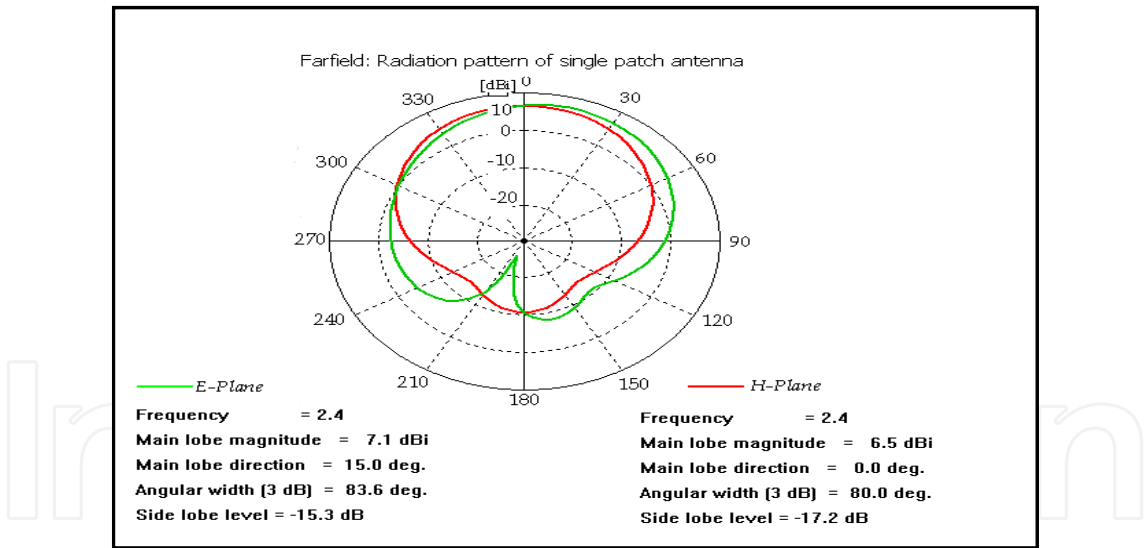


Fig. 3.4. E-plane and H-plane for single patch design

From the radiation pattern as shown in Fig 3, the normalized value of the radiation pattern which 50Ω input impedance will give half power beamwidth value. Half power beamwidth is a measurement of angular spread of the radiated energy. From this radiation pattern, the values at 3 dB for E-plane and H-plane are 94.9°and 99.6° respectively. The summary of the simulation results for single element patch design is shown in Table 3.2. Half power beamwidth for both E and H-Plane, directivity and gain that has extracted from radiation pattern are also shown in this table.



Type	Single patch
Return loss	-31.88 dB
Bandwidth	108.7 MHz (4.05%)
Directivity	6.11 dBi
Gain	2.56 dB
HPBW (E-Plane)	83.6°
HPBW (H-Plane)	80.0°

Table 3.2. Summary of simulation results for single patch antenna.

3.2.2 Square patch slanted +45° and -45° polarized

To gain insight into the behavior of dual polarized antenna, a single inset feed was designed for geometry slanted at +45° and -45° linear polarized. As indicated in the introduction, all work was carried out at 2.4 GHz which is implementing onto WLAN application.

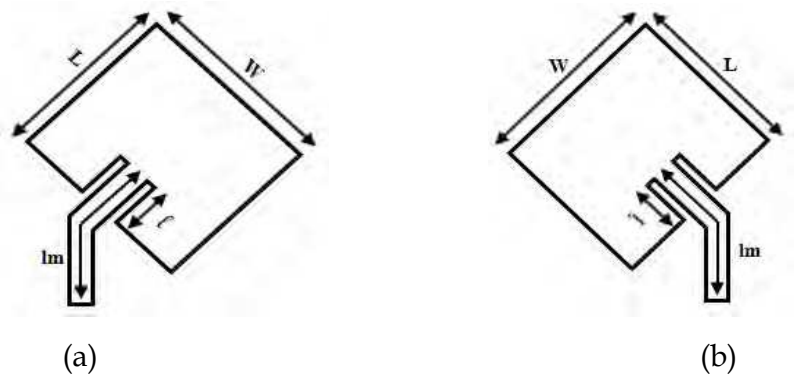


Fig. 3.5. (a) Layout of the +45° slanted polarization patch antenna  
(b)Layout of the -45° slanted polarization patch antenna

The basic single linear +45° and -45° polarized microstrip antenna configuration is shown in Fig 3.5. The baseline configuration uses a square patch inset-feed technique on the top layer. All dimension of a single patch +45° and -45° polarized microstrip antenna such as length, width and inset are calculated exactly using equation 3.11-3.20. Then, a single element patch is rotated at 45° for antenna slanted at +45° and 45° to produce polarized needed.

Hence, the width and length of single patch used in slant 45° and -45° are the same which its width, W and length, L equal to 27.67 mm. However, the inset length,  $\ell$  is changed due to the band element connected to the square patch. Since slant 45° and -45° have perpendicular polarizations, the antennas not have much effect on each other and give similar results in terms of return loss and bandwidth. The simulation of return loss and bandwidth of the design single 45° and -45° polarization are shown in Fig 3.6. All plots contain impedance data that has been normalized to 50 Ω. The resonant frequency was 2.4 GHz with return loss of -12.84 dB for single 45° and -16.24 dB for single -45°.

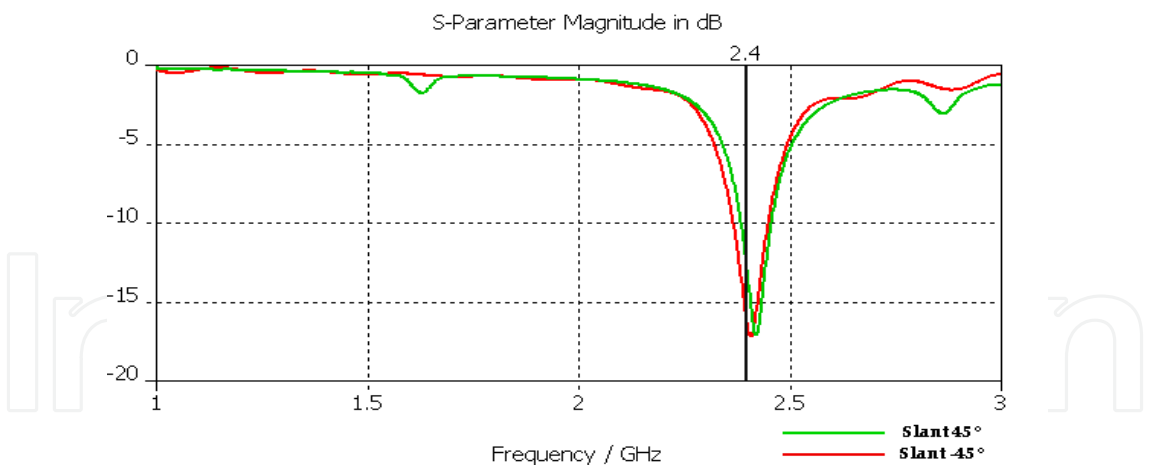


Fig. 3.6. Return Loss [dB] for 45° and -45° polarized antenna

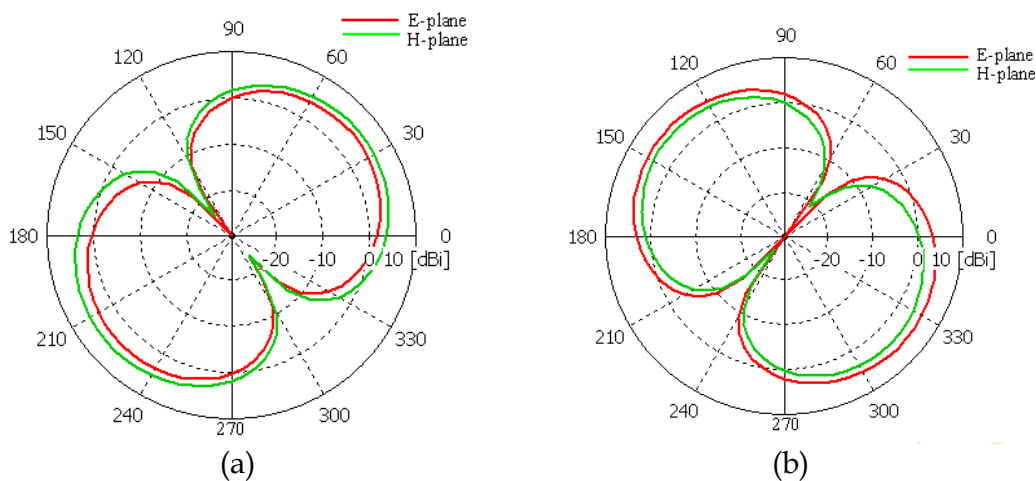


Fig. 3.7. (a) E and H-plane of the +45° slanted polarization patch antenna  
(b) E and H-plane of the -45° slanted polarization patch antenna

From the radiation pattern as shown in Fig 3.7, the normalized value of the radiation pattern will give half power beamwidth value. The summary of the simulation results for single element patch design is shown in Table 3.3. Half power beamwidth for both E and H-Plane, directivity and gain that has extracted from radiation pattern are also shown in the table.

Type	Single 45°	Single -45°
Return loss	-16.84 dB	-16.8 dB
Bandwidth	87 MHz (3.7%)	86 MHz (3.6%)
Directivity	5.69 dBi	5.71 dBi
Gain	2.56 dB	2.61 dB
HPBW (E-Plane)	83.4°	89.8°
HPBW (H-Plane)	89.8°	82.5°

Table 3.3: summary of simulation results for single 45° and -45° patch antenna.

3.3 Dual Polarized Array Antenna

3.3.1 1x2 Dual Polarized Array Antenna

After designed the slanted polarized for each  $+45^\circ$  and  $-45^\circ$ , the combination for both layouts can give the dual polarized radiation in term of array. A parallel or corporate feed configuration was used to build up the array. In parallel feed, the patch elements were fed in parallel by using transmission lines. The transmission lines were divided into two branches according to the number of patch elements. The impedances of the line were translated into length and width by using AWR Simulator. Fig 3.8, Fig 3.9, and show the circuit layout of the 1x2 array antennas with different position of the patch. In this project, the position of the patch is considered at  $45^\circ$  and  $-45^\circ$  to obtain dual linearly polarized.

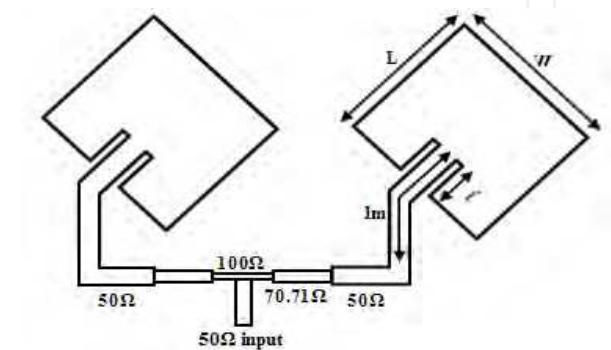


Fig. 3.8. Layout of the 1x2  $+45^\circ$  polarized array antenna

In Fig 3.8 a single  $+45^\circ$  polarized was combined using corporate feed network to produce an array antenna. The comparison result between single element and 1x2 array antenna was describe clearly in terms of return loss, radiation pattern and gain. Same like Fig 3.9, this structure was built using single  $-45^\circ$  polarized and combines with two elements to achieve polarization slant at  $-45^\circ$ .

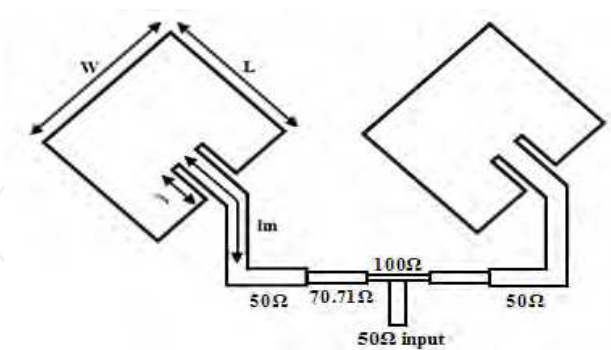


Fig. 3.9. Layout of the 1x2  $-45^\circ$  polarized array antenna

The simulation results for 1x2 array antennas slanted at  $45^\circ$  polarization were 103 MHz and  $-28.11$  dB for bandwidth and return loss respectively. While, the simulation result for 1x2 array antennas slanted at  $-45^\circ$  polarizations were 103 MHz and  $-31.82$  dB for bandwidth and return loss respectively. Fig 3.10 show simulation result for  $45^\circ$  and  $-45^\circ$  polarized 1x2 array antenna.

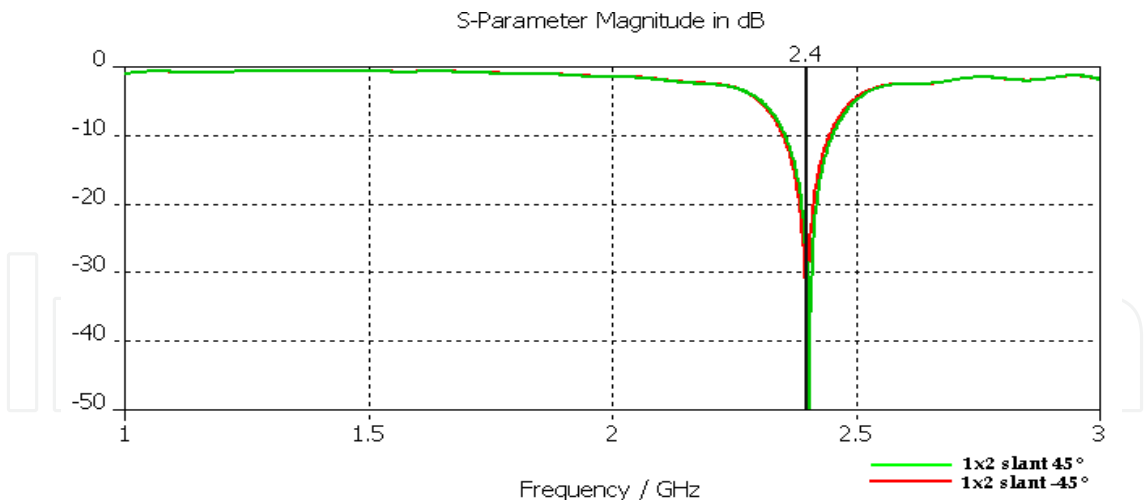


Fig. 3.10. Return Loss for 45° and -45° polarized 1x2 array antenna.

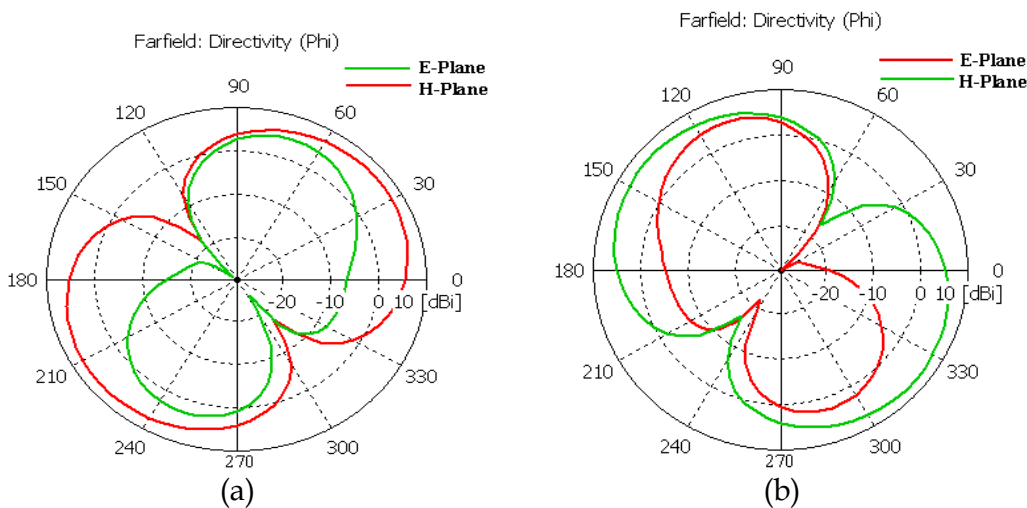


Fig. 3.11. (a) E and H-plane of the +45° slanted polarization patch antenna  
(b) E and H-plane of the -45° slanted polarization patch antenna

The resulting radiation pattern of the E-plane and the H-plane of the two element antenna array is shown in Figure 3.11 (a) and (b), respectively. It is clear from these figures that the array antenna demonstrates a more directive pattern with better half power beamwidth and gain compared to that of individual patch.

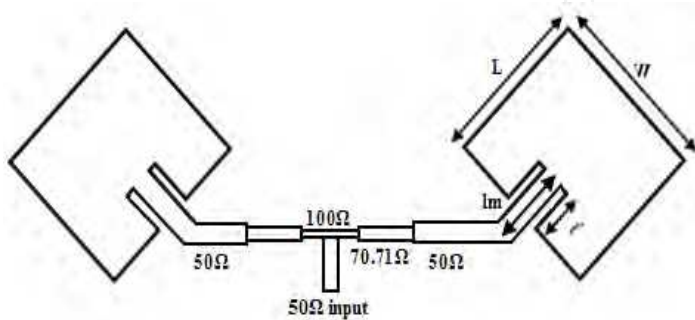


Fig. 3.12. Layout of the dual polarized 1x2 array antenna

Using built single patch slant at 45° and -45° polarization; 2-element array patch had designed and simulated in CST Studio Suite 2006 as shown in Fig 3.12. The array network is used to combine the 2 element of single patch antennas. A microstrip feed line has connected to the patch from the edge of the substrate.

An array of 1x2 dual polarized array antenna is build from combination of slant +45° and slant -45°. In order to combine, corporate feed again is involved to connect a single +45° and -45° polarized. According to the layout in figure 3.12, the antenna exhibits to have radiation of dual polarization pattern. The simulated return loss of the 1x2 dual polarization array antennas are shown in Fig 3.13. The simulation results for 1x2 dual polarization array antennas were 82.5 MHz and -21.31 dB for bandwidth and return loss respectively.

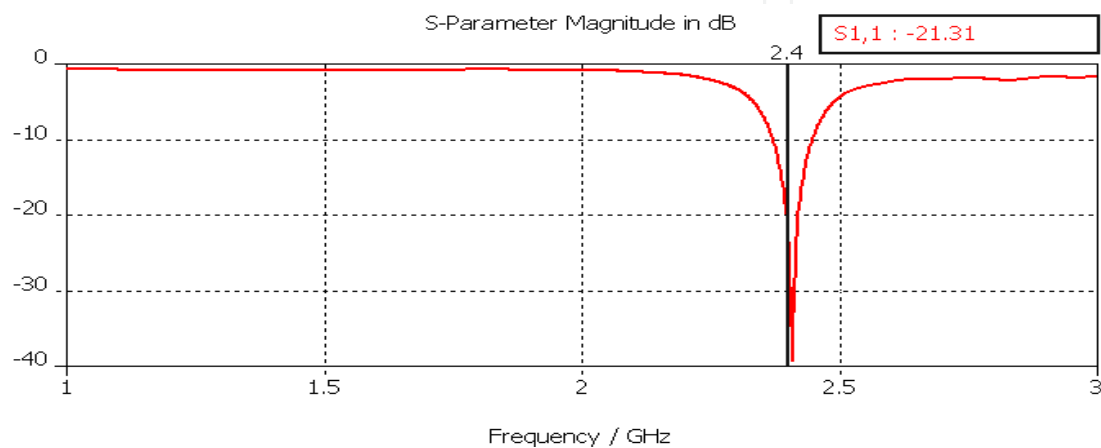


Fig. 3.13. Return Loss for dual polarization 1x2 array antenna.

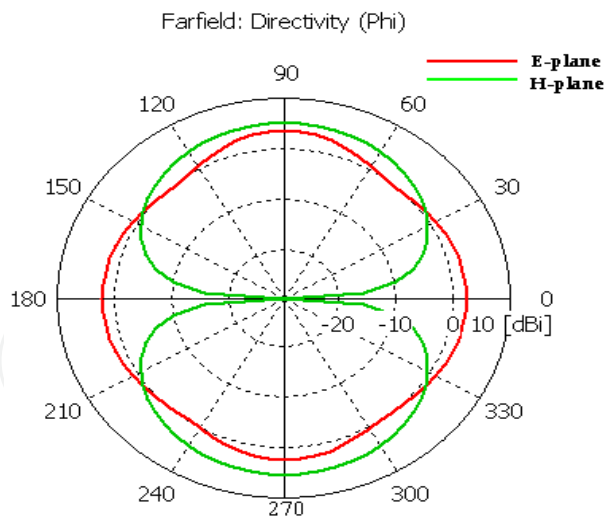


Fig. 3.14. Simulation radiation pattern of 1x2 dual polarization array antennas.

Fig 3.14 show the radiation pattern of the 1x2 dual polarization array antennas for E-plane and H-plane respectively. Overall, this design give better gain and directivity compared 1x2 array at slant 45° and -45° polarization antennas. The simulation of HPBW for E-plane is about 61.1°; while at H plane is about 89.9°.All simulation data for 1x2 array antenna designs are tabulated in Table 3.4.

Design	Return Loss (dB)	BW (%)	Gain	Directivity	HPBW (E-Plane)	HPBW (H-Plane)
45° polarized	-28.11	4.29 (102.3MHz)	2.98	7.82	57.5	89.8
-45° polarized	-31.82	4.29 (102.3MHz)	2.96	7.71	54.9	90
Dual-polarized	-17.72	4.42	3.09	8.18	61.1	89.9

Table 3.4. Simulation results for 1x2 array antennas

3.3.2 1x4 Dual Polarized Array Antenna

Based on the pervious design of 1x2 dual linear polarized a 1x4, 2x2 and 2x4 arrays was designed and simulated. The initial dimensions for dual linear polarization are the same as the single polarization element. The patch and feed dimensions were maintained from the 1x2 dual linear polarized designs when designing 1x4 arrays antenna. 1x4 array antennas had designed and simulated in CST Studio Suite 2006. A microstrip feed line has connected to the patch from the edge of the substrate. As mention before, the design center frequency is 2.4 GHz applied for WLAN application. The most important results of the array design that should be achieved are the return loss result, bandwidth result, radiation pattern results and gain result. The much element used for designing dual polarized the higher gain and performance can be achieved.

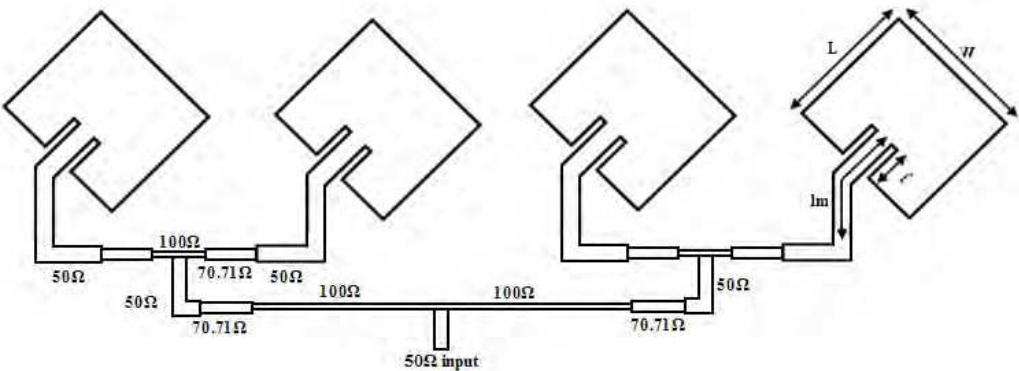


Fig. 3.15. Layout of the 1x4 +45° polarized array antenna

In Fig 3.15, two set of 1x2 array antenna slant at +45° polarized was combined using corporate feed network to produce an array antenna. The comparison result between single element and 1x2 array antenna was describe clearly in terms of return loss, radiation pattern and gain. Same like Fig 3.16, this structure was built using single -45° polarized and combines with two elements to achieve polarization slant at -45°.



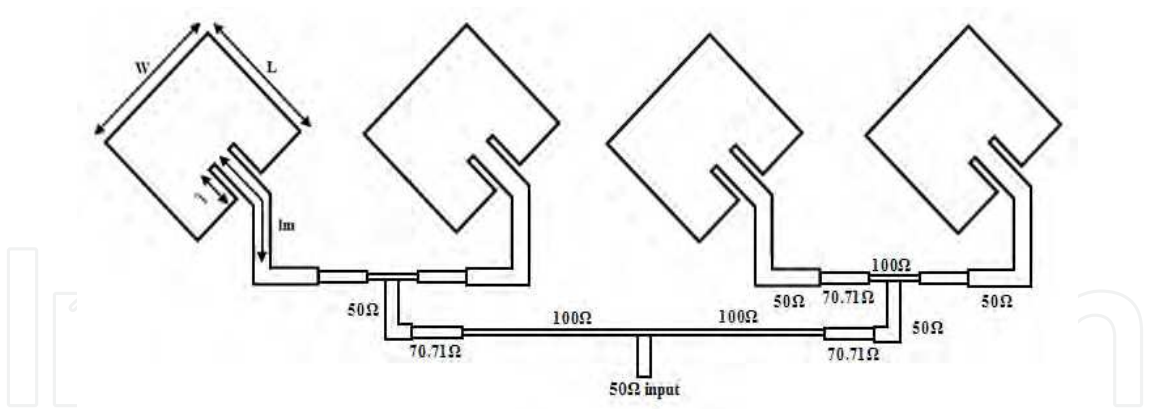


Fig. 3.16. Layout of the 1x4 -45° polarized array antenna

An array of 1x4 dual polarized array antenna is build from combination of 1x2 array antenna slant +45° and slant -45°. According to the layout in Fig 3.17, the antenna exhibits to have better radiation pattern and return loss compared to 1x2 dual polarized array antennas.

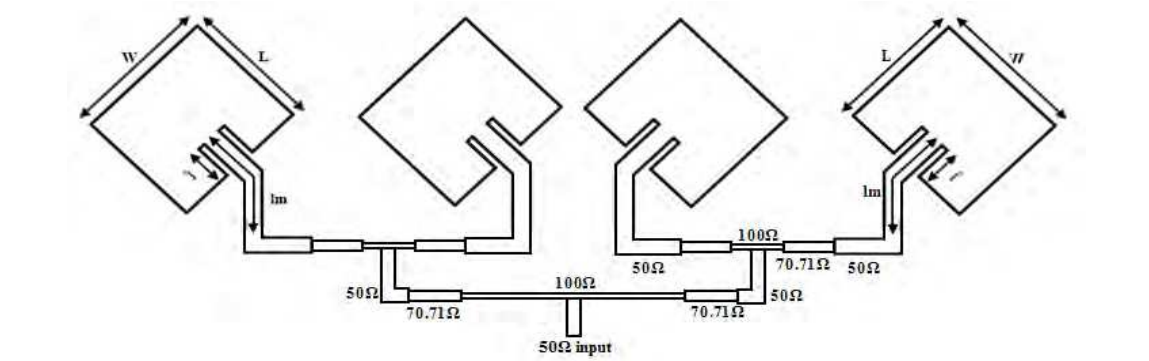


Fig. 3.17. Layout of the 1x4 dual liner polarized array antenna.

The simulated return loss of the 1x4 microstrip array is shown in Fig 3.18. The simulation results for 1x4 array antennas were 79.4 MHz and -25.74 dB for bandwidth and return loss respectively. Fig 3.19 shows the radiation pattern for 1x4 array antenna. Note in this radiation pattern is has consist of mutual coupling between the radiating elements.

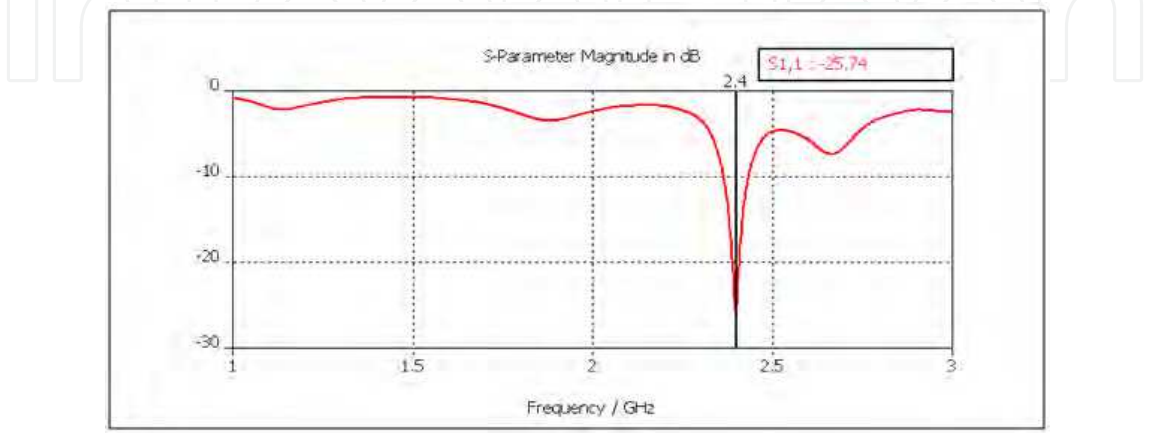


Fig. 3.18. Return Loss for dual polarization 1x4 array antenna.



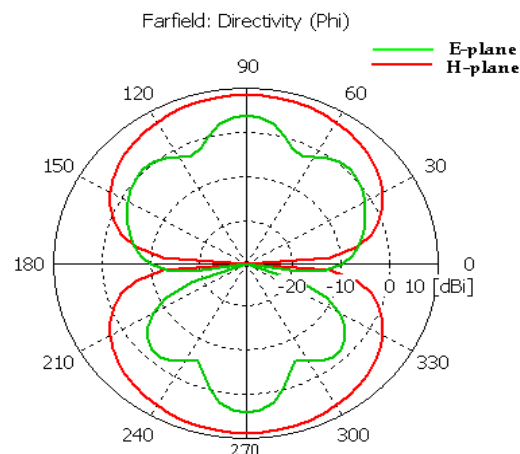


Fig. 3.19. Simulation radiation pattern of 1x4 dual polarization array antennas.

The simulation radiation pattern of the 1x4 dual polarization array antennas for E-plane and H-plane are shown, respectively. The HPBW achieved for the E-plane and the H plane is about 524.6° and 89° respectively. The HPBW shows that at H-Plane cut is better compared to E-Plane cut. Moreover, there is a null appears in E-Plane pattern result of 1x4 array patch design which decreases the HPBW lower than 2x2 dual polarization array antenna. At 2.4 GHz as shown in figure 4.24, the antenna directivity is about 8.673 dBi while antenna gain is about 5.01 dB.

3.3.3 2x2 Dual Polarized Array Antenna

As seen in Fig 3.20, the 2x2 dual linear polarized designs are fed by coax probe. This was integrated with 1x2 dual polarized array antenna and feed at centre of the quarter wave transmission line using coaxial technique. Compared with the expected result for a single element design, this result can be considered as a better result where a single microstrip element produces a very low gain. The most important results of the array design that should be achieved are the return loss, bandwidth, radiation pattern and gain result.

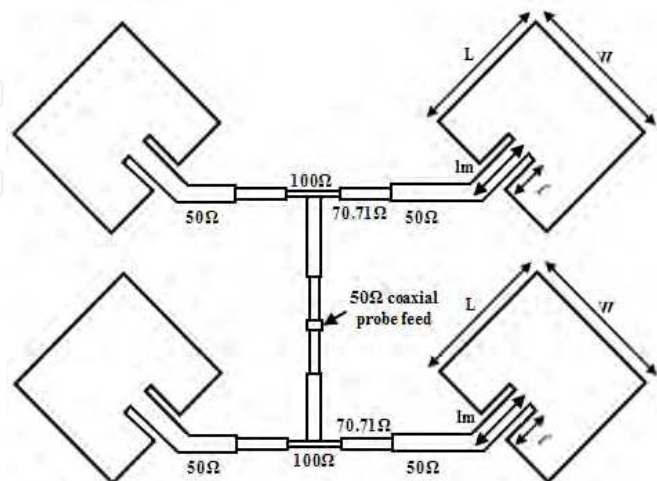


Fig. 3.20. Layout of the 2x2 dual linear polarized array antenna.

The simulated return loss of the 2x2 microstrip array is shown in Fig 3.21. As mention in pervious chapter the design was used coax probe compare to other design use transmission line technique. The square patch dimension was maintained from the single element design. The simulation results for 2x2 array antennas were 89 MHz and -37.45 dB for bandwidth and return loss.

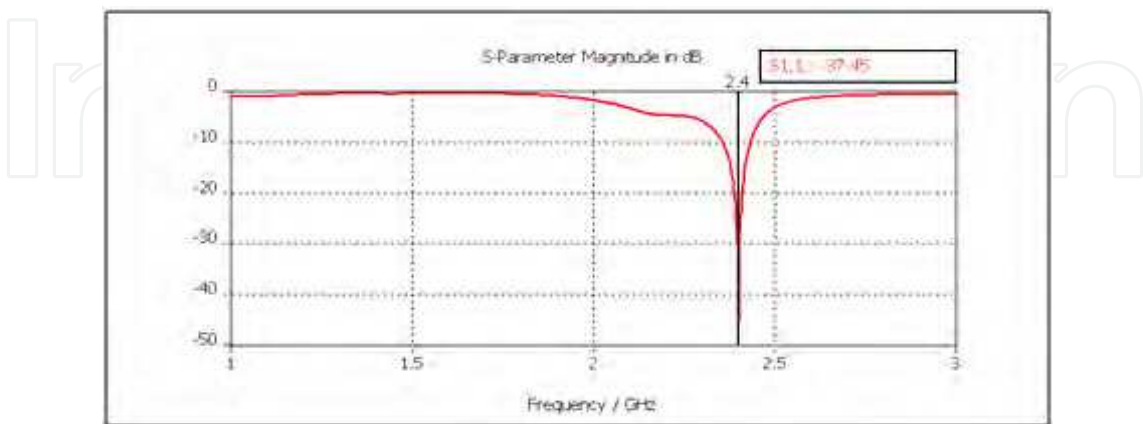


Fig. 3.21. Return Loss for dual polarization 1x4 array antenna.

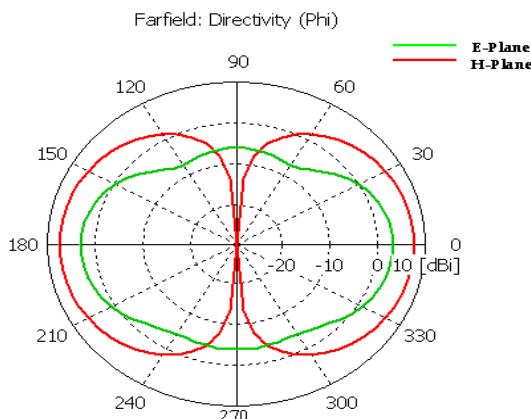


Fig. 3.22. Simulation radiation pattern of 2x2 dual polarization array antennas.

According to Fig 3.22, the antenna gain for this design is better comparing 1x2 array antennas which 1.2 dB higher. This radiation pattern show the E-Plane and H-Plane for 2x2 dual polarization array antenna. The HPBW show that at H-Plane cut is better compared to E-Plane cut. Moreover, there is a null appears in E-Plane pattern result of 2x2 array patch design. This may due to mutual coupling occurred in arrays, beside that each four elements in the array design configuration is facing the back of each other, which also influence in the null that appeared in the radiation pattern results.

3.4 Measurement result

3.4.1 Dual Polarized 1x2 Array Antenna measurement result

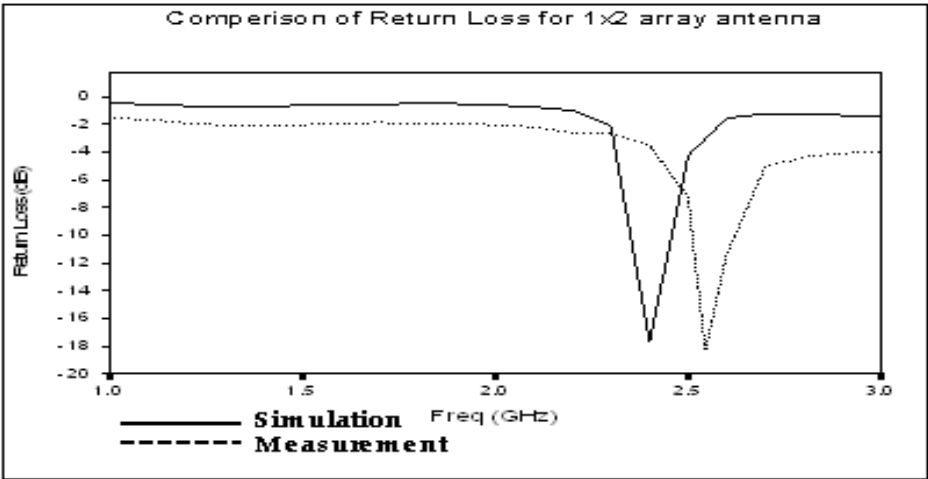


Fig. 3.23. Return Loss [dB] for 1x2 dual linear polarized array antenna.

The comparison between simulated and measured result was shown in Fig 3.23. The measured of return loss slightly different at desired frequency compare to simulated result. This because due to error on fabrication process. Since, the simulation result of the return loss has a value of -17.72dB at resonant frequency of 2.4GHz. While the fabrication results of the return loss has a value of -18.28dB at resonant frequency of 2.53GHz.

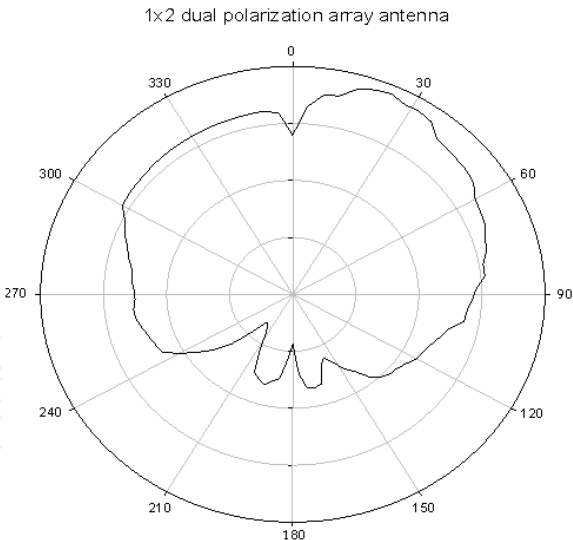


Fig. 3.24. 1x2 array antenna radiation pattern fabrication results

The radiation pattern for this antenna is presented in Fig 3.24, where it can be seen that the pattern seem like radiating in slant 45° and -45°. The gain of this antenna is 2.83 dB, which is lower than 0.26 dB from simulation result.

3.4.2 Dual Polarized 1x4 Array Antenna measurement result

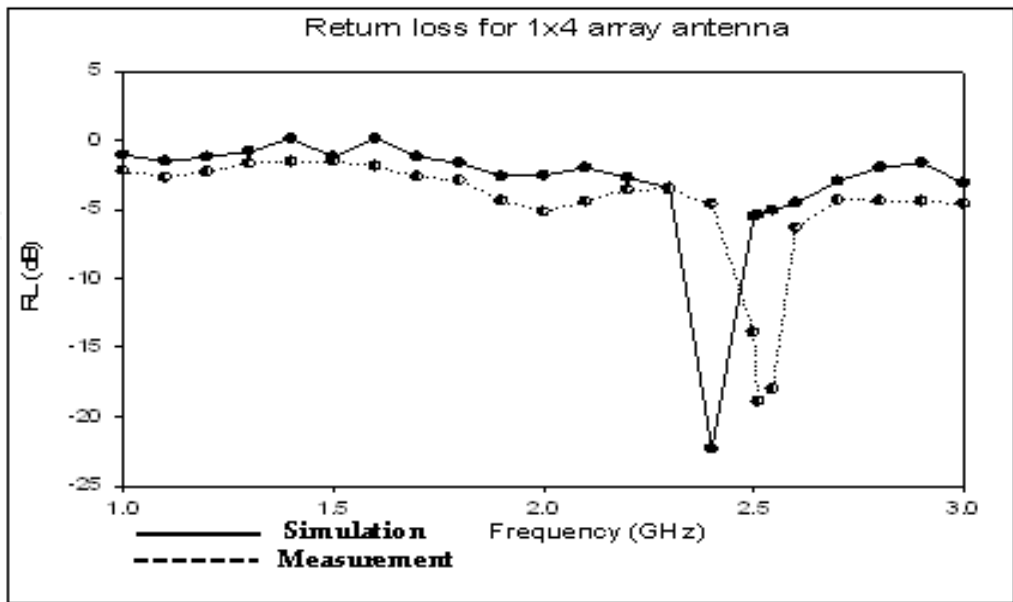


Fig. 3.25. Return Loss [dB] for 1x4 dual linear polarized array antenna.

According to Fig 3.25, the result of the return loss of the 4-elemnt array patch design has a good result at frequency of 2.5 GHz which is-23 dB. This result could be considered as a good result. Where at the resonant frequency of 2.45GHz which is the intended design frequency has a value of -9.8dB. However, the bandwidth of measurement value is lower than simulation which is only 3.03%.

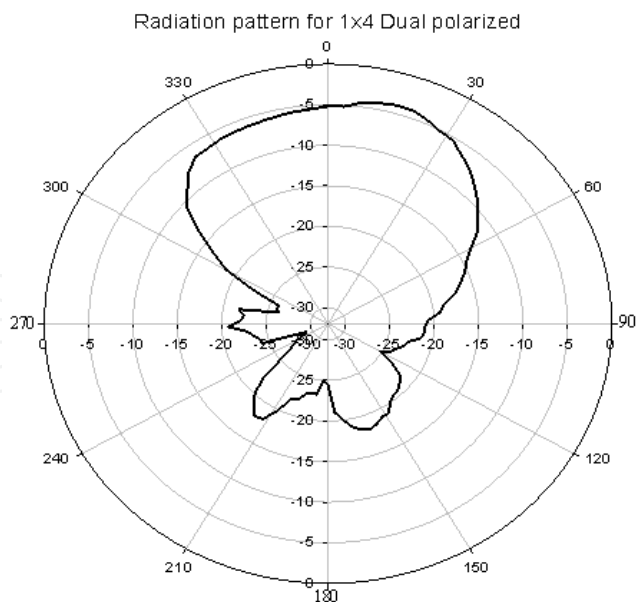


Fig. 3.26. 1x4 array antenna radiation pattern fabrication results

Fig 3.26 show the measurement radiation pattern of the 1x4 dual polarization array antennas. The HPBW achieved for the antenna is about 54.6°. At 2.4 GHz as shown in this pattern, the antenna gain is about 4.37 dB. From the measurement result, one can considered

that there is a variation in the resonant frequency which shift to 2.5 GHz compared to the simulation result. According to this variation, the other measurement method like radiation pattern of both the electrical field and magnetic field, gain and directivity will be applied using the resonant frequency of the return loss fabrication result. Since, the resonant frequency of 2.5 GHz has the best value compared to the intended resonant frequency of the design which is 2.4 GHz.

3.4.3 Dual Polarized 2x2 Array Antenna measurement result

The measurement result of return loss for 1x4 microstrip array is shown in Fig 3.27. The measurement results for 1x4 array antennas were 3.615% and -23.74 dB for bandwidth and return loss respectively. The resonant frequency for fabrication result has shifted by 2.49 GHz which is 5.4% from the simulation resonant frequency. The root cause of the shift is could be due to the FR4 board has  $\epsilon_r$  that varies from 4.0 to 4.8. In practical world, a material which has varying  $\epsilon_r$  along a length/width/height, will affect resonant frequency to shift. The other factors affecting etching accuracy such as chemical used, surface finish and metallization thickness also could be the reason for the resonant frequency shifting. According to Fig 3.28, the beam pattern for 2x2 dual-polarizations has lower sidelobe level compared to 1x2 and 1x4 antennas, but the bandwidth at resonant frequency was very narrow. The narrow bandwidth characteristic of 2x2 antennas can be improved by adjusting the distance of array network, which is quarter wavelength between the patches. This enhancement was achieved without any significant degradation of the beam patterns and bandwidths. The HPBW achieved for the antenna is about 87°. At 2.4 GHz as shown in Fig 3.28, the antenna gain is about 3.57 dB.

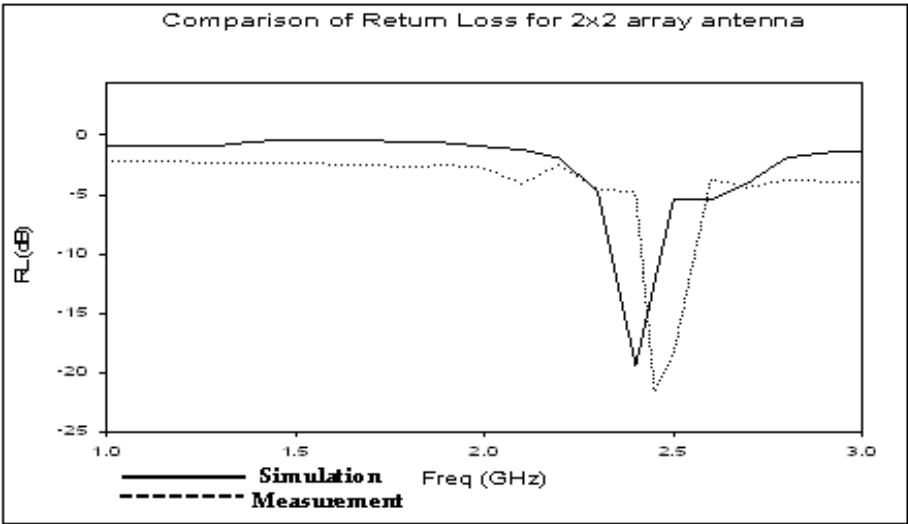


Fig. 3.27. Return Loss [dB] for 2x2 dual linear polarized array antenna.

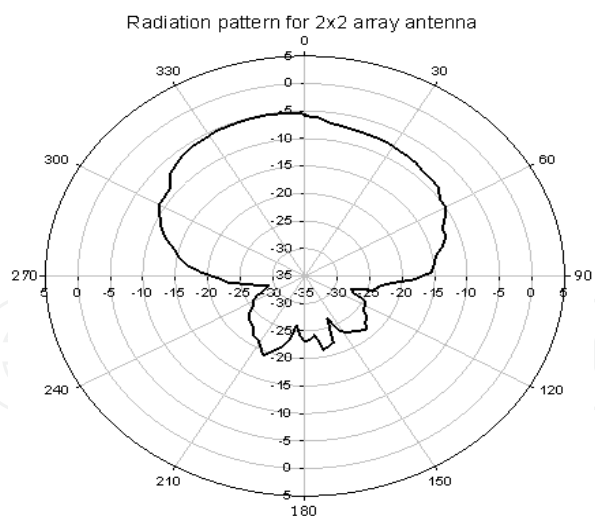


Fig. 3.28. 2x2 array antenna radiation pattern fabrication results

3.4.5 Comparison of the simulation and measurement result

Table 3.5 shows a comparison between simulation and fabrication results of the radiation pattern. According to the variation that occurred in the return loss result, the radiation pattern results were measured by adjusting the resonant frequency at 2.53GHz instead of 2.44 GHz. From this table, one can notice that the HPBW for simulation and fabrication results are in a good agreement.

The gain of the single element antenna was almost 2.21 dBi, and the gain of 1x2 arrays was 2.83 dBi. By designing more patches, which were 2x2 and 1x4 array antennas, the enhancement of gain achieved were 3.57 dBi and 4.37 dBi, respectively. The radiation pattern for 2x2 dual-polarizations has lower sidelobe level compared to 1x2 and 1x4 antennas, but the bandwidth at resonant frequency was very narrow. The narrow bandwidth characteristic of 2x2 antennas can be improved by adjusting the distance of radiation, which is quarter wavelength between the patches. This enhancement was achieved without any significant degradation of the radiation patterns and bandwidths.

	1 x 2		1 x 4		2 x 2	
	Sim	Meas	Sim	Meas	Sim	Meas
Resonant Freq(GHz)	2.4	2.54	2.4	2.51	2.4	2.48
Return loss (dB)	-17.6	-17.3	-21.1	-18.19	-19.4	-21.03
VSWR	1.35	1.18	1.37	1.16	1.24	1.17
BW (%)	4.42	3.45	4.41	4.77	5.46	3.61
Gain	3.09	2.83	5.01	4.37	4.29	3.57

Table 3.5. A comparison of the radiation pattern results for simulation and fabrication

#### 4. Conclusion

A high gain of 3 design microstrip patch antennas oriented at  $45^\circ$  and  $-45^\circ$  was proposed to obtain dual polarization. The antennas were operated at resonant frequency, around 2.4GHz with low VSWR. The return loss, radiation pattern and antenna gain have been observed for single, 1x2, 1x4 and 2x2 dual-polarization microstrip patches array antennas. It can be concluded that the responses from the 2x2 and 1x4 patches were better compared to the 1x2 array antenna and single patches antenna. Although the results from the measurement were not exactly the same as in the simulation, there were still acceptable since the percentage error was very small due to the manual fabrication process.

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## **Trends in Telecommunications Technologies**

Edited by Christos J Bouras

ISBN 978-953-307-072-8

Hard cover, 768 pages

**Publisher** InTech

**Published online** 01, March, 2010

**Published in print edition** March, 2010

The main focus of the book is the advances in telecommunications modeling, policy, and technology. In particular, several chapters of the book deal with low-level network layers and present issues in optical communication technology and optical networks, including the deployment of optical hardware devices and the design of optical network architecture. Wireless networking is also covered, with a focus on WiFi and WiMAX technologies. The book also contains chapters that deal with transport issues, and namely protocols and policies for efficient and guaranteed transmission characteristics while transferring demanding data applications such as video. Finally, the book includes chapters that focus on the delivery of applications through common telecommunication channels such as the earth atmosphere. This book is useful for researchers working in the telecommunications field, in order to read a compact gathering of some of the latest efforts in related areas. It is also useful for educators that wish to get an up-to-date glimpse of telecommunications research and present it in an easily understandable and concise way. It is finally suitable for the engineers and other interested people that would benefit from an overview of ideas, experiments, algorithms and techniques that are presented throughout the book.

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M. S. R Mohd Shah, M. Z. A Abdul Aziz, M. K. Suaidi and M. K. A Rahim (2010). Dual Linearly Polarized Microstrip Array Antenna, Trends in Telecommunications Technologies, Christos J Bouras (Ed.), ISBN: 978-953-307-072-8, InTech, Available from: <http://www.intechopen.com/books/trends-in-telecommunications-technologies/dual-linearly-polarized-microstrip-array-antenna>

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Unit 405, Office Block, Hotel Equatorial Shanghai  
No.65, Yan An Road (West), Shanghai, 200040, China  
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元  
Phone: +86-21-62489820  
Fax: +86-21-62489821

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